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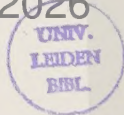
PREDICTION OF GROWTH PATTERN AFTER ANKLE FRACTURES IN CHILDREN

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SUMMARY

The importance of different factors in predicting the posttraumatic growth was evaluated using multivariate statistical techniques.

The material consisted of 55 children with physeal fractures of the distal tibia and/or fibula. The posttraumatic growth pattern was determined by roentgen stereophotogrammetry. Forty-nine cases showed various types of growth patterns. Six cases showed no growth on the fractured or intact side and were excluded.

The predictors used included sex, skeletal maturity, traumatological and anatomical classification, displacement, treatment, and associated tibial shaft fracture.

Prediction of a specific growth pattern, of four types, could be made only with low accuracy. Considered independently, only skeletal maturity was important in predicting the individual growth pattern.

Separation of the growth patterns into two groups - with symmetrical growth, initial and temporary growth retardation, and growth stimulation in one group, and progressive growth retardation, and growth arrest in the other - resulted in higher predictive accuracy. Comparing the predicted outcome with the actual and misclassified outcomes resulted in two out of three fractures being correctly classified. Considered individually, treatment, displacement, and skeletal maturity were important.

In summary, prediction of the posttraumatic growth pattern is possible to some extent. The highest risk of developing a deformity is associated with injuries involving both distal tibia and fibula and requiring open reduction because of large displacement. The importance of the Salter-Harris classification separately was insignificant.

The limited accuracy in predicting the posttraumatic growth pattern after ankle fractures in children indicates that in many cases there are grounds for radiographic follow-up to detect growth disturbance. Using roentgen stereophotogrammetry, it is possible to register growth disturbance before deformity has developed.

INTRODUCTION

The growth pattern after physeal injuries has been studied both experimentally (7, 13, 23, 24, 29, 43) and clinically (1, 12, 14, 16, 25, 38, 39, 41, 54). Bisgard and Martenson (9) stressed the influence of infection and open reduction on future growth. Aitken (3) and Spiegel et al. (54) concluded that exact reduction was of minor importance, which is contrary to the conclusions of Suessenbach and Weber (55) and Salter and Harris (48) as regards physeal-epiphyseal injuries.

The fracture anatomy is important (2, 48) and has constituted the basis for several studies. However, the value of anatomical classifications has been discussed (12, 33-35, 39).

In contrast to the Salter-Harris classification concerning physeal injuries, some authors (1, 18, 52) have suggested that the prognosis of physeal injuries varies depending on the region of injury.

Traumatological classifications of ankle fractures (14, 19, 25) were presented based on the genetic production of different fracture types, and also included information about the region of physeal damage and the extent of the injury. These classifications (14, 25) were considered to have some prognostic value.

Moreover, skeletal maturity (34, 54), amount of displacement (35, 39), disturbed vascularization (45), adequacy of reduction (42, 55), type

of osteosynthesis (13, 45, 51), and length of the immobilization period (8, 26, 44) were considered to be prognostically relevant.

Earlier investigations (33, 34, 35) demonstrated the posttraumatic growth pattern of physeal fractures of the ankle with a roentgen stereophotogrammetric technique (49). Five types of growth pattern were found: symmetrical growth (→), initial growth stimulation (↗), initial and temporary growth retardation (↘), initial and progressive growth retardation (↙), and initial and permanent growth arrest (↓).

Using multivariate statistical techniques, the present study evaluated the significance of different factors in predicting the growth pattern after ankle fractures in children.

MATERIALS AND METHODS

Fifty-five children with a physeal fracture through the distal tibia and/or fibula were investigated. In all, there were 66 physeal fractures. Of these, three children had a physeal fracture through the distal tibia and an associated fracture of the tibial shaft (Table 1). The posttraumatic growth pattern was registered with a roentgen stereophotogrammetric technique (12, 33, 34, 35, 49). The patients were examined at intervals between one and twelve months with increasing periods of time between examinations.

In 51 cases the registrations started within six months after fracture. In one case with significant growth on the intact side, the registration started 39 months after fracture: a considerable shortening of the fibula (2.7 cm) was present when the registration started (case 52). In six cases no growth was registered on either side during the initial period, and these cases were excluded from statistical analysis.

Table 1. Clinical summary.

Case	Type of trauma	Stage	Ass. tibial shaft fracture	Sex	Age at injury	Skeletal maturity
1	Supination-eversion	I-IIa	-	♀	10	12
2	"	I-IIa	-	♀	12	14
3	"	I-IIb	-	♂	8	10, 5
4	"	I-IIb	-	♂	9	8, 5
5	"	IIIa	-	♂	14	14
6	"	IIIa	-	♀	14	13
7	"	IIIa	-	♀	11	12
8	"	IIIa	-	♂	13	14
9	"	IIIb	-	♀	8	9, 5
10	"	IIIb	-	♀	10	10
11	"	IIIb	-	♀	11	12
12	"	IIIb	-	♀	11	12
13	"	IIIb	-	♂	12	12
14	"	IIIb	-	♂	12	13
15	"	IIIb	-	♂	12	13, 5
16	"	IIIb	-	♀	13	13
17	"	IIIb	-	♂	13	14
18	"	IIIb	-	♂	14	13, 5
19	"	IIIb	-	♂	15	14
20	"	IVa	-	♂	13	14
21	"	IVa	-	♀	13	14
22	"	IVb	-	♀	10	11
23	"	IVb	-	♀	10	11
24	"	IVb	-	♂	10	11
25	"	IVb	-	♀	11	12
26	"	IVb	-	♂	11	14
27	"	IVb	-	♂	13	13
28	"	IVb	-	♀	13	14
29	"	IVb	-	♂	13	15
30	"	IVb	-	♂	14	15

Salter - Harris		Displacement of physal fracture (s)		Treatment in addition to plaster	Observation time in months	Growth Pattern	
Fib	Tib	max Fib	mmi Tib			Fib	Tib
-	III	-	<2	-	2 - 18	→	↘
-	III	-	<2	-	4 - 13	→	→
z(IV)	-	<2	-	-	2 - 27	(	→
z(IV)	-	<2	-	-	2,5 - 38	(	→
-	II + III + IV	-	2-5	-	2,5 - 29	)	↘
-	II + III + IV	-	<2	-	2,5 - 12	→	→
-	II + III + IV	-	<2	-	3,0 - 12,5	→	→
-	II + III + IV	-	<2	-	2 - 20	↘	→
-	II	-	2-5	closed red	2 - 19,5	)	(
-	II	-	<2	-	2 - 24	(	(
-	II	-	<2	-	3 - 17,5	)	(
-	II	-	<2	-	2 - 13	→	↘
-	II	-	<2	-	6 - 7,5	(	(
-	II	-	<2	-	1,5 - 16	)	→
-	II	-	<2	-	3 - 10	(	(
-	II	-	<2	-	3 - 11	(	
-	II	-	<2	-	3 - 20	)	(
-	II	-	<2	-	3 - 24	)	(
-	II	-	<2	-	3,5 - 13,5	(	→
-	III + IV	-	>5	open red pinning	0 - 16	)	↘
-	II + III + IV	-	>5	open red wire staple	2,5 - 17,5	(	→
-	II	-	2-5	closed red	3 - 12	(	→
-	II	-	>5	"	15 - 17		
-	II	-	>5	"	3 - 12	)	(
-	II	-	>5	"	3 - 26,5	(	↘
-	II	-	>5	"	2 - 30	(	→
-	II	-	2-5	"	2,5 - 12	)	(
-	II	-	>5	"	3 - 10		
-	II	-	2-5	"	3 - 11	→	
-	II	-	>5	"	2 - 22,5	(	(

continued

Case	Type of trauma	Stage	Ass. tibial shaft fracture	Sex	Age at injury	Skeletal maturity
31	Supination-adduction	I	-	♂	10	11,5
32	"	II	-	♀	6	6,5
33	"	II	-	♀	6	7
34	"	II	-	♀	8	9
35	"	II	-	♀	9	8
36	"	II	-	♂	11	11,5
37	"	II	-	♀	12	13
38	"	II	-	♀	13	13,5
39	"	II	-	♂	13	12
40	"	II	-	♂	14	14
41	"	II	-	♂	15	14
42	Pronation-abduction	IIa	-	♂	8	8,5
43	"	Ib	-	♀	12	13
44	Pronation-eversion	III-IVa	-	♂	10	10
45	"	"	-	♂	11	11,5
46	"	"	-	♂	12	12,5
47	"	"	-	♂	13	13,5
48	"	"	-	♂	14	15
49	"	"	-	♂	16	14,5
50	"	"	-	♀	13	14
51	Atypical	II*	-	♀	11	11
52	"	II*	-	♂	9	9
53	"	I+	comminuted	♀	10	10
54	"	I+	longitudinal	♀	10	11
55	"	I+	"	♀	12	12

* indicates injury of both distal tibia and fibula. See text!

+ no injury of fibula. See text!

++ instability of one bone marker distal fibula

Salter - Harris		Displacement of physal fracture (s)		Treatment in addition to plaster	Observation time in months	Growth Pattern	
Fib	Tib	max Fib	mm Tib			Fib	Tib
	-	<2	-	-	3 - 19		
I	III	<2	<2	-	2 - 12		
I	z(IV)	<2	2-5	closed red pinning	2 - 31, 5		
I	III	<2	<2	-	2 - 19		
I	z(IV)	<2	2-5	open red pinning	0, 2 - 27		
I	III	<2	<2	-	2, 5 - 25		
I	III	<2	<2	-	3 - 4, 5		
II	III	<2	<2	-	4 - 9		
II	III	<2	2-5	open red pinning	3 - 29		
I	III	<2	<2	-	3 - 11		
I	III	>5	>5	open red screws, pinning	3 - 17, 5		
I	-	<2	-	-	6 - 26, 5		
-	I	-	<2	-	3 - 14		
-	II	-	>5	closed red	4 - 21		
-	II	-	>5	open red pinning	2, 5 - 7, 5		
-	II	-	2-5	closed red	5 - 24		
-	II	-	>	closed red	3 - 22		
-	II	-	<2	-	7 - 16		
-	II	-	>	closed red	2 - 15		
-	II	-	2-5	closed red	8 - 18		
I	z(IV)	2-5	2-5	closed red	3 - 32		
IV	-	2-5	-	-	39 - 51(56)		
-	IV		2	-	6 - 47		
-	II+III+IV		2	-	3 - 5	2 ⁺⁺	
-	?(III)		2	-	4 - 28		

A discriminant analysis was carried out using the BMDP-79 program (20). This is a program that ranks, in a stepwise manner, the prognostic factors in descending order according to their reliability for predicting the group membership of a patient. The prognostic factors (predictors, variables) are listed in Table 2. Owing to the limited number of cases, the traumatological classification was separated into four variables (position of foot, type of trauma, site of injury, and stage). Fractures described anatomically with a combination of different types according to Salter-Harris (48) were coded with the highest classification type used. Thus, a supination-eversion Stage IIIa (triplane fracture), classified as Salter-Harris Type II+III+IV, was registered as Type IV.

One case (case 54) with an external rotatory longitudinal fracture (21) in combination with a triplane fracture was classified as being due to supination-eversion.

Five cases were impossible to classify traumatologically, resulting in two evaluations: one including all cases (60 fractures) and one including cases with all variables (55 cases).

The growth patterns were separated into both four and two groups. The separation of symmetrical growth and initial and temporary growth retardation was considered to be of limited clinical significance, and hence these growth patterns were combined (Group A) in two investigations. The other growth patterns (growth stimulation, progressive growth retardation, and growth arrest) were considered separately (Groups B, C, and D). In two additional investigations, Groups A and B and Groups C and D were combined, resulting in only two groups (Groups A+B and C+D).

Table 2. Key to the different variables used.

Variable	Explanation	Assigned Value	
X_1	Sex	Male	= 1
		Female	= 2
X_2	Skeletal maturity	Years	
X_3	Position of foot at injury	Supination	= 0
		Pronation	= 1
X_4	Type of trauma	Rotation	= 0
		Bending	= 1
X_5	Stage	Fracture of tibia or fibula	= 1
		Fracture of tibia and fibula	= 2
X_6	Site of physeal fracture	Tibia	= 0
		Fibula	= 1
X_7	Anatomical classification	Salter-Harris Type I	= 1
		Type II	= 3
		Type III	= 3
		Type IV	= 4
X_8	Displacement	< 2 mm	= 0
		2 - 5 mm	= 1
		> 5 mm	= 2
X_9	Treatment	No reduction	= 0
		Closed reduction	= 1
		Open reduction	= 2
X_{10}	Associated tibial shaft fracture	No	= 0
		Yes	= 1

Differences in the size of the groups are considered in the discriminant analysis by using the Bayesian classification procedure (5). It is also obvious that the selected predictors are more or less interdependent. By applying a stepwise version of the discriminant analysis, it is possible to identify a smaller subset of significant variables for use in the discriminant function. The discriminant function is a linear equation:

$$D = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + \dots$$

The probability of a certain patient developing a growth pattern according to the preceding groupings can be calculated by using the child's discriminant score (D).

The accuracy of an investigation has been determined by using the "jack-knife" method. This means that the data of each patient is again tested by using the equations derived from data for all the other patients (15).

RESULTS

I. All cases included, four result variables (Groups A, B, C, D)

The first step in the multivariate analysis was to compare predictors with different groups resulting in an F-value that is not influenced by other predictors. An F-value exceeding 4.0 was regarded as significant.

It was found that skeletal maturity, treatment, and stage had the highest values, however, not exceeding 4.0 for any predictor (Table 3-1).

The highest skeletal maturity was found among cases with initial and permanent growth arrest, followed by cases with symmetrical growth or initial and temporary growth retardation, and progressive growth retardation. Cases treated with closed or open reduction showed a tendency to develop progressive growth retardation or growth arrest, whereas

Table 3-1. All cases included, four result variables.

Variable	F-value
Skeletal maturity	3.388
Treatment	3.083
Stage	2.929
Displacement	1.874
Associated tibial shaft fracture	1.867
Sex	1.203
Anatomical classification	0.271
Site of physeal fracture	0.190

Table 3-2. All cases included, two result variables.

Variable	F-value
Treatment	9.575
Displacement	5.191
Skeletal maturity	3.359
Associated tibial shaft fracture	2.432
Stage	1.872
Anatomical classification	0.834
Sex	0.341
Site of physeal fracture	0.001

isolated injuries of the distal tibial or fibular growth plate showed a tendency to develop growth stimulation.

Further analysis, resulting in the predicted outcomes compared with the actual and misclassified ("jackknife"), showed only 24 out of 60 correctly classified cases, indicating that the posttraumatic growth pattern was difficult to predict with the chosen predictors. According to change, 15 cases should be correctly classified.

II. All cases included, two result variables (Group A+B, Group C+D)
Treatment and displacement showed an F-value exceeding 4.0 when considering predictors independently of one another. As in the previous evaluation, very low F-values were found for sex, anatomical classification, and site of physeal fracture (Table 3-2).

Stepwise discriminant analysis was more accurate than in the previous analysis: 40 out of 60 cases were correctly classified.

The discriminant function for this computation was:

$$D = 9.65 - 0.92x_1 - 0.46x_2 - 1.52x_6 - 0.73x_7 - 1.39x_9 + 2.41x_{10}.$$

Here, the patient is likely to show normal growth initial and temporary growth retardation, or initial growth stimulation of varying length of time if the discriminant score (D) ≥ 0 . If the discriminant score is < 0 , the patient is classified as "likely to show a progressive growth retardation or growth arrest".

The probability of developing either type of growth pattern is calculated using the equation $p = 1/[1 + \exp(-D)]$.

Table 3-3. Cases not classified according to variables X_3 .
 X_4 (55 physeal injuries), four result variables.

Variable	F-value
Skeletal maturity	4.369
Treatment	3.091
Type of trauma	1.986
Stage	1.782
Displacement	1.732
Sex	1.236
Anatomical classification	0.643
Associated tibial shaft fracture	0.569
Site of physeal fracture	0.307
Position of foot at injury	0.265

III. Cases not classified according to variables X_3 , X_4 (55 physeal injuries), four result variables (Groups A, B, C, D)

Introducing position of the foot and type of trauma did not appreciably change the F-values of the other variables. None of the introduced variables proved to be of any importance when considered independently (Table 3-3). Analysis according to the "jackknife" method showed 19 cases of 55 correctly classified; thus, there was no improvement when compared with the first analysis.

IV. Cases not classified with variables X_3 , X_4 (55 physeal injuries), two result variables (Group A+B, Group C+D)

No major changes were found compared with the analysis reported in section II. Treatment, displacement, and skeletal maturity showed a significant F-value (Table 3-4). Analysis according to the "jackknife"

gave an accuracy of 39 correctly classified cases of 55. The discriminant function was rather similar to that computed in section II above.

$$D = 10.49 - 1.20x_1 - 0.50x_2 - 1.10x_6 - 0.72x_7 - 1.50x_9 + 2.72x_{10}.$$

Thus, if a boy with skeletal maturity at age ten years had a supination-adduction injury Stage I of Salter-Harris Type I through the distal fibula treated by plaster fixation, its discriminant score will be 2.47, which means that the patient is likely to show a growth pattern according to Group A+B. The probability of developing this type of growth

Table 3-4. Cases not classified with variables X_3 , X_4 (55 physeal injuries), two result variables.

Variable	F-value
Treatment	9.510
Displacement	4.116
Skeletal maturity	4.012
Anatomical classification	1.992
Stage	0.935
Associated tibial shaft fracture	0.771
Site of physeal fracture	0.466
Type of trauma	0.316
Position of foot at injury	0.138
Sex	0.065

pattern is calculated at:

$$\frac{1}{1 + e^{-2.47}} = 0.92$$

On the other hand, if a girl with skeletal maturity at age ten years has a supination-adduction injury Stage II with a Salter-Harris Type I injury through the distal fibula and a Type IV injury through the distal tibia, treated by open reduction because of displacement, the discriminant score for the distal fibula will be -1.73 and for the tibia -2.79, indicating that the patient is likely to show a growth pattern according to Group C+D in both distal fibula and tibia. The probability of developing a growth pattern according to Group A+B in the distal fibula is :

$$\frac{1}{1 + e^{1.73}} = 0.15$$

and the probability of developing a similar growth pattern in the distal tibia is:

$$\frac{1}{1 + e^{2.79}} = 0.06$$

Thus, the failure of the Salter-Harris classification to classify some Type I injuries is compensated for in the discriminant function by adding factors such as sex, skeletal maturity, site of injury, and treatment. However, the discriminant function computed here is not completely accurate, and three out of ten patient failed to be correctly classified in the present material.

DISCUSSION

Prediction studies have been made earlier as regards cardiovascular disease (5,6,40), malignant diseases (11,30,50), infectious disease (32), rheumatoid arthritis (22), and hip fracture rehabilitation (15,56). Lombardo and Harvey (39) found a significant increase in growth disturbance

after displaced physeal fractures about the knee, but the results reported from earlier studies of ankle fractures in children (25,54) were not tested statistically. Further, conventional roentgen examinations were used sometimes making determination of the genesis of a deformity difficult, as redisplacement after reduction is a recognized phenomenon after some types of injuries (25,35).

The analysis reported in sections II and IV above showed a high F-value for treatment. However, this variable exhibits a high degree of dependency, because only displaced fractures were reduced and those had mainly concomitant tibio-fibular injuries. This resulted consistently in disappearance of Stage and displacement from the discriminant function.

Remaining displacement after reduction was not evaluated in this investigation; a displacement exceeding 2 mm was present in four cases (cases Nos. 9,39,46, and 47) showing a variable growth pattern. Thus, from the present material no conclusion about the importance of an exact reduction could be drawn. The high F-value associated with treatment might suggest that the operative skill can be further improved, whereas the properties of those injuries treated with some kind of reduction might suggest damage of the growth plate at the time of injury as being determinative. Some injuries (cases Nos. 35 and 45), with large displacement and treated with closed or open reduction, showing a favorable growth pattern in the distal tibia would probably have developed deformity, if not reduced, due to lack of remodelling or premature closure of the growth plate. Moreover, restoration of joint congruity is important (54).

Some authors (3, 54) do not believe that it is possible to restore a favorable growth pattern by exact reduction. However, this problem might be viewed somewhat antithetically: large displacement and high Stage indicate a high risk injury; but if the extent of the physeal injury is limited, a favorable prognosis can be obtained only by gentle and exact reduction with no or minimal damage to the growth plate.

Skeletal maturity was discussed earlier as an important factor (34,54). Here, growth stimulation occurred at the lowest mean age of skeletal

maturity (mean age 10.8 years), progressive growth retardation at a somewhat higher mean age (11.1 years), symmetric growth or initial and temporary growth retardation around aged twelve, and permanent growth arrest at about aged 13 years. This might be due to a higher growing potential (large remaining growth and a high growth rate) in the younger child. Moreover, the younger child has a thicker and more uniform growth plate that is probably more resistant to trauma than that of an older child.

Determination of skeletal maturity according to conventional methods show some variability compared with the time of growth plate closure in the distal tibia and fibula. A better determination of skeletal maturity would probably increase the accuracy of the discriminant analysis and would be important when determining the remaining growth.

Prediction of the future growth after physeal fractures is a difficult problem, and recommendations have been made to follow up also Types I and II according to Salter-Harris, notwithstanding the supposed prognostic value of this classification (17,45,47). Failure of the Salter-Harris classification has been attributed to the presence of a hidden Type V injury (45). However, introduction of a Type V injury combined with any other type makes the Salter-Harris classification less valuable for prognostic purposes at the time of injury. Furthermore Peterson and Burkhart (44) narrowed the diagnostic criteria for this injury and also questioned its existence. As regards ankle fractures, this type of injury, if it exists, must be very rare, for it was not found in two retrospective studies, (25,36) that included more than 600 fractures. Moreover, a Type V injury according to the criteria defined by Peterson and Burkhart (44) was not described in another study including 237 fractures (54).

In the present study the Salter-Harris classification could not alone in any of the analyses significantly separate the physeal fractures on the basis of different posttraumatic growth patterns. In the discriminant function this classification is of importance, but here also other factors and interdependency must be considered.

The traumatological classification includes variables such as position of foot at injury; type of trauma; Stage; and, to some extent, site of physeal fracture. This separation was necessary because of the restricted number of cases. Further, to equalize the importance of supination-eversion, pronation-eversion Stage IV, and supination-adduction Stage II injuries, the staging was simplified. Testing of the fracture types, including the total information about each type, would require a larger material including also subgrouping of supination-eversion and pronation-abduction injuries (25,33), and result variables such as presence and type of asymmetrical growth. However, in the present transformation of the traumatological classification, no variable alone was of prognostic importance.

Growth stimulation after diaphyseal fractures is a well-known phenomenon (4,10,27,28,31,46,53). All the fractures in the present study manifested growth stimulation in spite of the presence of an associated physeal fracture of the distal tibia. However, none of the physeal fractures showed a displacement exceeding 2 mm, none was reduced, and none had an associated fibular injury suggesting a favorable growth pattern according to the discriminant function.

Symmetrical growth and initial and temporary growth retardation were summarized as no problems of clinical importance are to be expected.

Initial and temporary growth stimulation is usually associated with a favorable result. A slight asymmetrical growth may occur, but rarely correction of angular deformities of the distal tibial epiphysis after a physeal fracture (33). However, in one case with an associated shaft fracture of the tibia (case No. 55) and a persisting recurvation at healing, an antecurvation of the distal tibial epiphysis during subsequent growth almost totally reduced the deformity. Premature closure of the growth plate may occasionally occur (37) resulting in correction or overcorrection of deformities (35).

The consequences of progressive growth retardation and growth arrest are dependent on the amount of the remaining growth.

In summary, it was possible to predict the future growth pattern with an accuracy of seven out of ten cases correctly classified according to the "jackknife" method using two result variables. Knowledge of the traumatological classification adds some additional information: intra-articular supination-eversion injuries occur at high skeletal maturity with low remaining growth. Pronation-eversion Stage III-IV and supination-adduction Stage II injuries might show a progressive varus tilting, whereas supination-eversion injuries might show a recurvation. Valgus deformity was reported after pronation-abduction Stage II injuries (25). Ankle fractures involving both the distal tibia and the fibula requiring open reduction because of displacement were found here to be likely to undergo progressive growth retardation or growth arrest. According to the traumatological classification, supination-adduction and pronation-abduction Stage II injuries, supination-eversion Stage IVb, and pronation-eversion Stage ^{III}IV injuries might fulfill these criteria (25) - injuries that can appear also when the remaining growth is considerable.

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